6-1906

Crop Rotation

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South Dakota Agricultural College

Bulletin 98 June, 1906

SOUTH DAKOTA

Agricultural College

EXPERIMENT STATION

BROOKINGS, SOUTH DAKOTA

CROP ROTATION

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CROP ROTATION

John S. Cole

INTRODUCTION

An extensive experiment in crop rotation has been under way at the South Dakota Experiment Station since 1897. This experiment was begun by Professor E. C. Chilcott, now of the Department of Agriculture at Washington, and was carried on continuously by him until the close of the last fiscal year. The writer has, however, been connected with the work as an assistant in the Department for six years. The field work has since its beginning been uninterruptedly in charge of Mr. William West, foreman of the Experiment Station farm. One bulletin, No. 79, which is now out of print, was published by Professor Chilcott in 1903, giving some of the results of the first five years of the experiment.

It is perhaps needless to say that results from an experiment in crop rotation become increasingly more valuable the longer the experiment runs. It cannot be said, therefore, that the experiment is in any way finished, but it is believed that the importance of the work justifies the publication of results up to date.

It is not the purpose in this bulletin to make an exhaustive study of all the results, or of all the different rotations. Such a task would be almost limitless. We will confine ourselves (1) To a brief discussion in a general way of the results from each rotation; (2) To a more extended study of the results from some of the shorter rotations, especially in regard to alternate cropping to wheat and corn, wheat and summer fallow, and wheat and a legume, vetch; (3) To the effect of applying manure with varying frequency to land that grows wheat alone, and to land in which corn enters into the rotation; (4) The effect of introducing a sod crop into the rotation, and (5) The influence of the immediately preceding crop upon the yield of wheat, oats and barley.

OUTLINE OF THE EXPERIMENTS

(Adapted with some changes from Bulletin No. 79)

In the spring of 1896 a field of about eight and one-half acres was selected for crop rotation experiments. It is not definitely known just how long it had been under cultivation, but certainly not less than fifteen years. Wheat, oats and corn had been the principal crops raised. Very little manure had been applied.

The soil is an unmodified glacial drift known to geologists as the Iowa sheet, and consists of clay, sand and boulders, with a large percentage of lime, particularly in the subsoil. It is what would generally be called a sandy loam and would be considered a good corn soil for this locality, but a little too light for a first class wheat soil. The character of the soil is very similar to that found over a large portion of the state east of the Missouri river.

Water is found in this vicinity in veins of glacial gravel at a depth of about twenty-five to thirty feet. The formation from the surface down to this depth is a compact glacial clay.

The surface of the field is nearly level, entirely free from depressions, "draws," drains, or peculiarities of any kind. It is so located that it does not receive the washings from adjacent fields to any appreciable extent.

This field was divided into seventy one-tenth acre plats, each two chains long and fifty links wide, or two rods by eight rods. There are five series, each containing fourteen plats. The series are separated by driveways, each twenty-five links wide, and the plats by alleys five links wide. The driveways are kept graded, slightly higher in the center than near the sides next the plats, thus forming two shallow surface drains or gutters which carry off any excess of surface water. The alleys are kept cultivated and free from all vegetation during the growing season. The corners of each plat are permanently marked by pieces of water pipe driven deeply in the ground, with the upper ends just at the surface. During the growing season wooden stakes, painted and properly labeled, are placed at each corner.

On these seventy plats were laid out twenty-two separate rotations or systems of cropping. These range from continuous cropping to wheat both with and without manure, up to five year rotations. Each rotation contains as many plats as there are years in the rotation. A four year rotation, for instance, covers four plats lettered A, B, C and D. The crop that is on plat D this year will be on C next year, on B the next year, and on A the year after that. All the other crops follow in the same way.

Every rotation is in effect a small farm on which the particular rotation under consideration is followed. Every plat is sown, tended and harvested by itself, with ordinary farm machinery and under exactly the same conditions as larger sized fields.

The plats are plowed in the fall, usually in September, crosswise by series. This necessarily involves plowing the corn ground and potato ground. We have found by other experiments that where the corn has been properly cultivated and kept clean there is on the average very little diffrence to be seen in the following crop whether the corn ground is plowed or whether it is drilled in without plowing. The ground is plowed at depths varying in different years from about five to seven inches. As early as possible in the spring the ground is harrowed twice with an ordinary steel lever harrow.

In seeding the plats to small grain each plat is sown separately with a common fourteen bar disc drill, care being taken to see that the seeding extends slightly beyond the limits of each plat. As soon as the grain is well up each plat is carefully trimmed to exact dimensions with a hoe and garden line. Like precautions are taken with other crops in order that each plat shall contain exactly one-tenth of an acre of crop.

Each grain plat is harvested and threshed separately. The grain is threshed from the shock as soon as it is in proper condition with an ordinary thirty-two inch separator specially constructed to facilitate cleaning out. The product of each plat is weighed as it comes from the field, and the grain weighed as it comes from the machine. If it contains an

unusually large amount of chaff or foul seed, which is not often the case, it is cleaned before taking the weight.

Corn is drilled in rows one way. It is given good clean cultivation with the drag, weeder and cultivator, each in its proper season. When the corn is ripe or frosted it is cut with the corn binder, shocked up in the field and allowed to stand until dry. When well dried out, usually some time in November, it is hauled to the barn and husked. The yield is based on the weight of the ears at that time, seventy-two pounds being allowed for a bushel.

When certain crops are to be fed off on the land, they are fenced, and hogs, sheep or cattle turned on them about the time the crop has reached its maximum growth and before it has begun to ripen. They are then kept on it until the crop no longer furnishes them any feed. A record is kept of the number of head of stock on a plat, the number of days it takes them to feed it off, and their gain or loss in weight.

The same variety of wheat is grown upon all wheat plats, the same variety of oats on all oat plats, and so on with all the crops. The seeding of all the plats of any one kind of grain is done on the same day and at the same rate per acre. In short, as far as possible, every factor not involved in the rotation itself is eliminated.

All summer fallowed plats are plowed in July before any weeds have ripened their seeds, and are plowed again with the other plats in the fall. They are given no other cultivation during the season. When peas are to be plowed under it is done just before they begin to ripen. This is sometimes done at the same time the summer fallow plats are plowed, but usually it is a little later.

No manure or fertilizer is ever applied to any of the plats, except in the few rotations where it is expressly stated that manure is used. During the first few years of the experiment well rotted manure was applied to these in the spring as a top dressing at the rate of twenty tons or ten loads per acre. We are now, instead of this, spreading the same amount of fresh manure from the horse barn on the stubble before plowing and turning it under in the fall.

CLIMATIC CONDITIONS

A complete meteorological record has been kept and the mean temperature and precipitation for the growing months and the year are here given:

METEOROLOGICAL TABLES

Table 1—Temperature

	April	May	June	July	August	Seasonal 5 Months	Annual
1897	44.1	56.1	63.1	71.2	63.6	59.6	41.7
1898	45.6	54.5	66.3	70.4	69.6	61.3	43.6
1899	43.8	55.2	64.8	69.2	69.4	60.5	41.6
1900	50.2	60.0	66.1	68.2	74.0	63.7	44.2
1901	47.1	57.0	65.9	76.2	70.4	63.3	44.0
1902	42.0	58.2	60.2	69.6	65.1	59.0	42.3
1903	45.2	56.6	62.2	67.0	65.2	59.2	41.5
1904	40.8	55.0	62.4	65.2	65.2	57.7	41.2
1905	42.3	51.2	63.8	66.0	70.2	58.7	42.3
Average for nine years....	44.5	55.9	63.8	69.2	68.1	60.3	42.5

Table 2—Precipitation

	April	May	June	July	August	Seasonal 5 Months	Annual
1897	2.45	.83	3.86	4.32	3.59	15.05	22.94
1898	.88	5.15	1.94	1.56	2.78	12.31	16.65
1899	3.36	3.38	5.42	.73	3.25	16.14	20.23
1900	1.68	1.23	1.62	5.10	4.00	13.63	24.56
1901	1.40	1.80	4.51	1.66	2.94	12.31	19.76
1902	1.60	2.66	3.17	2.75	5.30	15.48	21.83
1903	1.00	4.53	4.16	3.30	4.25	17.24	24.62
1904	1.78	1.82	4.30	1.91	.93	10.74	15.48
1905	1.01	6.14	6.09	.98	4.54	18.76	26.77
Average for nine years...	1.68	3.06	3.90	2.48	3.51	14.63	21.43

THE ROTATIONS

It will be noticed that wheat enters into every rotation, and that in several it occurs twice. This is not because wheat is or should be grown on every farm, but because it was considered desirable to have some one crop in every rotation for purposes of comparison. Where wheat occurs twice in one rotation one is designated as Wheat-1 and the other as

Wheat-2. As these two crops have been raised under identically the same conditions and in succeeding years on the same ground, a comparison of the yields of the two will serve to throw much light upon the effects of the immediately preceding crop.

In Bulletin No. 79 the yields of only the three crops, wheat, oats and barley, were given. In the present publication we will give the average yields of all the harvested crops. The yields of the first year, 1897, are not included in any of the averages. As the crop of 1896 was the same for all the plats, the yields for 1897 could not of course be affected in any way by the rotations.

No record was obtained for the crop of 1899 for any of the oat or barley plats, nor for the wheat in rotations No. 1 to 10 inclusive, on account of a tornado that mixed the grain in the shock so it was impossible to separate it and tell to which plat it belonged. The yield for that year was a very good one, while that for 1900, which is included in the averages, was the poorest for many years. The yield of barley for 1900 is not included, as it was a total failure. This was partially due to too early spring sowing. It was cut down by frost, and dry weather following prevented its recovery. The crop of everything but potatoes was lost in 1903 by hail. The storm came July 15th, or just before oats and barley were ripe. After the storm the plats were all cut over with a mower and the straw hauled off.

One of the most perplexing questions in comparing results from a considerable number of rotations is what standard to use as a basis of comparison. This must in any case be an arbitrary standard. We might compare all systems of cropping with the one that has given the best results, and there are a good many things to be said in favor of such a comparison. Or we might with equal propriety compare all yields of a crop such as wheat with the yields obtained by continuous cropping to that cereal. Or we might use the average yield of the state or of the county as a basis for comparison. Or in an extensive experiment like the one under consideration we might use the average yield from all the rotations as a standard, and it is this latter that we will make the basis of comparison in this bulletin.

No attempt is made to show which are the most profitable crops, or which crops any farmer should grow. The cost of production, and the purpose of the farm, whether it is to grow crops for the market or for feed, are questions that must enter into any such consideration and that make it necessary for every farmer to determine for himself what crops shall enter into his rotations and in what proportions. Our object is to show as far as we can what crops deplete the soil of its fertility and reduce its productivity and what crops maintain those qualities, and further, if certain crops are to be grown, the combinations or order of succession that is calculated to give the best yields or the greatest immediate returns.

In Table No. 3 is given the average yields per acre of all the crops in rotations No. 1 to No. 22 inclusive, for all the years in which a crop has been secured.

Table No. 3

CROPS	Average Yield per Acre		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat	2580	14.7	2.91
Oats	2557	51.7	1.54
Barley	2205	43.2	1.06
Corn	2200	33.6	.91
Millet	3047	20.4	2.48
Flax	2550	13.8	3.30
Peas	3228	24.7	2.17
Potatoes	.....	104.9	.....

Using this table as a basis for comparison, we will take up a discussion of each separate rotation.

Five Year Rotation—No. 1

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Flax	2510	13.4	3.33
Barley	2332	47.7	1.02
Millet	3333	20.6	2.69
Wheat	2642	17.1	2.57
Corn	2112	33.3	.88

This rotation of flax, barley, millet, wheat and corn has proven a very good one. Flax following corn has been a good crop except for two years when there was flax wilt in the land. Whether the wilt lived in the land the five years intervening between the flax crops, or whether it advanced through the field faster than the succession of crops advanced the flax is not known. It is quite likely, however, that once in five years is too often to bring flax on the same field.

The barley following flax in this rotation has been one of our best yielding plats of barley. Its yield exceeds the general average of all barley plats by 4.5 bushels of grain and 127 pounds of straw per acre. The only barley that has equaled this plat in yield is in rotation No. 6, which has exceeded it by one bushel per acre. But in No. 6 there are in the course of five years two restorative crops introduced into the rotation, peas and corn fed off on the land.

The yield of grain from the millet plat has been only two-tenths of a bushel greater than the average, but the straw has exceeded the average by a little over 300 pounds per acre. This excess of straw is probably due to the fact that this millet plat has been a little more weedy than has some of the others.

The yield of wheat in this rotation is 2.4 bushels per acre above the average of the wheat plats. It is in fact exceeded in yield by the wheat in only two other rotations, wheat-2 in No. 9 and the wheat in No. 18. This is strong evidence in the further support of the fact that flax does not exhaust the fertility of the soil more than does other crops.

Corn in this rotation has been just about an average crop.

Five Year Rotation—No. 2

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat-1	2632	15.9	2.76
Oats	2772	49.3	1.75
Peas (fed)	.....	.....	.....
Wheat-2	2617	14.9	2.93
Potatoes	.....	104.9	.....

While the average yields from the different crops in this ro-

tation have been good, it is not an entirely satisfactory system of cropping. Both wheat crops and the oat crop have been inclined to lodge in seasons when the moisture has been plentiful. This tendency has been more pronounced in wheat-2 following peas fed off on the ground than it has in wheat-1, which follows the potato crop. A glance at the table will show that the same weight of straw has produced an average of one bushel more grain per acre following potatoes than it has following peas pastured off.

Five Year Rotation—No. 3

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Oats	2753	54.6	1.57
Wheat-1	2431	14.5	2.80
Fallow	.....	.....	.....
Wheat-2	2722	15.8	2.88
Corn	1924	33.0	.81

Oats following corn in this rotation have been a good crop, averaging 3.9 bushels per acre more than the average of all oat plats. The yield of straw has been 196 pounds per acre more than the average for oats.

Wheat-1 is the best crop of wheat following oats in any of the rotations. Wheat-2 is exactly an average crop of wheat following summer fallow. Perhaps the most interesting thing in this rotation is a comparison of the yield of these two wheat crops. Wheat-2, which is the crop preceded by a fallow, has produced an average of nearly 33 pounds more straw and 1.3 bushels more grain per acre than has wheat-1, which is preceded by a crop of oats.

Five Year Rotation—No. 4

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat-1	2817	16.1	2.90
Barley	2312	43.3	1.11
Peas (plowed under)	.....	.....	.....
Wheat-2	2947	15.5	3.17
Corn	1857	27.1	.95

This rotation introduces the growth of peas as a green manure crop. Whatever may be the ultimate effect on our soil of plowing under a crop for green manure, it can not be considered a profitable practice in the light of immediate results. Comparing wheat-1, which follows corn, with wheat-2, which follows peas plowed under, it will be seen that wheat-1 has produced from a slightly smaller amount of straw six-tenths of a bushel more grain per acre than has wheat-2. As the crop of corn is below the average of the corn crops, and the yield of barley is only equal to the average of the barley plats, it can not be said that plowing under the crop of peas has stimulated the growth of crops other than wheat in the rotation.

Comparing this rotation with No. 3, which has a summer fallow in place of the peas plowed under, we find that the yields of both the wheat and the corn following the first and second years after the fallow in No. 3 are better than the yields of the corresponding crops following peas plowed under in No. 4.

Five Year Rotation—No. 5

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat	2981	15.6	3.17
Oats	2923	52.1	1.75
Corn	2740	36.7	1.03
Flax	2592	13.5	3.26
Millet (fed)	.....	.....	.....

For one who wishes to grow these five crops no better combination or order of succession could be recommended. The yields of all the crops have been above the average. While the millet has been pastured off on the land, so no figures can be given of its yield, it has been a matter of observation nearly every year that it was the best plat of millet in the field.

The high average yields in both this rotation and in No. 1 proves that the general idea that flax is hard on the land and that a good crop can not be produced after flax is wrong.

Five Year Rotation—No. 6

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat-1	2836	14.9	3.16
Barley	2452	48.7	1.05
Peas	3508	28.8	2.02
Wheat-2	2920	13.0	3.74
Corn (fed)	.....	.....	.....

This rotation embraces the same crops as does No. 4. In No. 4 the peas are plowed under, in No. 6 they are harvested. In No. 4 the corn is harvested, in No. 6 it is pastured off on the ground, "hogged off," as it is sometimes called.

The results from the two rotations are very puzzling and hard to interpret. In No. 4 the yield of both crops of wheat is good and that of barley is poor. In No. 6 the wheat yields are poor and the barley has given the best yield of any barley plat in the rotations. The one point of agreement in both rotations is that in each of them the crop of wheat following corn is better than the crop of wheat following peas.

Four Year Rotation—No. 7

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat-1	2005	12.7	2.63
Corn	2196	35.6	.85
Wheat-2	2468	14.5	2.65
Oats	2323	49.6	1.47

The results from this rotation have not been satisfactory. The yield of wheat-2 following corn is the lowest with one exception of any plat of wheat following that crop. Wheat-1, which follows oats, is the lowest yielding plat of wheat in any rotation. It hardly seems possible that these poor yields can be due to any difference in the soil itself. Rotation No. 8 lies by the side of this one, and No. 9 joins it on the end, being separated from it only by a road one rod wide. All of them are on a level prairie soil that appears to be very uniform.

Four Year Rotation—No. 8

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat	2253	13.6	2.77
Corn	2281	35.5	.88
Oats	2521	52.5	1.50
Millet	2940	21.4	2.29

This rotation has given very nearly average yields. The corn, oats and millet are each slightly above the average for those crops, but the wheat is a little below the average of all wheat plats.

Four Year Rotation—No. 9

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat-1	1958	14.5	2.25
Corn (manured)	2513	40.0	.87
Wheat-2	2958	17.5	2.81
Oats	2407	55.6	1.35

This rotation is exactly the same as No. 7, except that in this one the ground is manured before it is planted to corn. As was mentioned under No. 7, the two rotations join on the end and, as far as one can see, the natural soil conditions of the two are equal. The difference in yield of the crops in the two rotations must be attributed to the effects of an application of ten loads of stable manure to the acre once in four years.

This treatment has produced an average crop of corn of 40 bushels per acre. This yield is the heaviest obtained on any of the corn plats, and is 4.5 bushels per acre more than the crop in rotation No. 7.

The yield of wheat following corn is 17.5 bushels per acre. This is a gain of three bushels per acre over the corresponding wheat crop in No. 7, and is 1.6 bushels per acre more than the average of all the wheat plats following corn. This yield of wheat is exceeded by the wheat in only one other rotation,

wheat in No. 17, grown on land which is cropped to corn every other year.

The yield of oats following the wheat in No. 9 is 6 bushels per acre greater than the yield of the corresponding crop in No. 7. This crop has to its credit the heaviest yield of any one of the eight plats of oats in the twenty-four rotations.

Wheat-1, which follows the oats, the fourth year from the application of the manure, is the best plat of wheat following oats in any of the rotations. It has produced an average yield of 1.8 bushels per acre more than the corresponding crop in No. 7.

Summing up, we have an increased yield of 4.5 bushels of corn the first year, 3 bushels of wheat the second year, 6 bushels of oats the third year, and 1.8 bushels of wheat the fourth year, from the effects of an application of manure to the corn crop that enters into the rotation every fourth year. This is the average for the first eight years of this rotation, but as the full effects of a rotation cannot be felt until it has been once around, the following comparison by rounds of the three four-year rotations No. 7, No. 8 and No. 9 has been prepared.

First Round 1898-1901

Rotation No. 7

Crops	Wheat-1	Corn	Wheat-2	Oats
Bushels per acre	12.5	28.7	16.0	37.0

Rotation No. 9

Crops	Wheat-1	Corn*	Wheat-2	Oats
Bushels per acre	12.9	25.7	18.5	38.6

Rotation No. 8

Crops	Wheat	Corn	Oats	Millet
Bushels per acre	14.8	27.4	41.9	13.2

* Manured.

Second Round 1902-1905

Rotation No. 7

Crops	Wheat-1	Corn	Wheat-2	Oats
Bushels per acre	12.9	44.8	12.9	61.5

Rotation No. 9

Crops	Wheat-1	Corn*	Wheat-2	Oats
Bushels per acre	16.0	54.1	16.9	72.6

Rotation No. 8

Crops	Wheat	Corn	Oats	Millet
Bushels per acre	12.3	46.3	66.3	15.2

* Manured.

We have already compared these rotations for the average of the whole eight years, but the above tables show that it is in the second round that the true difference in the value of the rotations is brought out. It will be noted that the effect of the application of manure in No. 9 was not marked on the rotation as a whole during the first four years, or its first round, but that in the second round, while the yields of No. 7 and No. 8, neither of which receive any manure, remain very close together, the yields of all the crops in No. 9, in which the corn is manured, stands away above them both in a class by themselves. Another difference not shown in the yields, but which may in a measure account for them, is the observed fact that while at first the crops all ripened at the same time, the crops in No. 9 now ripen about three days earlier than do the corresponding crops in either No. 7 or No. 8.

Three Year Rotation—No. 10

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat	2047	12.9	2.63
Corn	2130	34.0	.87
Oats	2385	50.5	1.47

This rotation may be compared with No. 15, which has two crops of wheat and one of corn. The average yield of corn in each rotation has been the same, 34 bushels, which is only four-tenths of a bushel more than the average of all the corn plats. In this rotation the corn is followed by a crop of oats, which has given an average yield of 50.5 bushels per acre. In No. 15 the corn is followed by wheat, which has averaged 14.3 bushels per acre. In each of the rotations the third crop is wheat. The average yield of this crop is the same in each rotation, 12.9 bushels per acre.

The only choice between the two rotations in point of average returns is whether the corn shall be followed by oats with an average yield of 50.5 bushels per acre, or whether it shall be followed by wheat with an average yield of 14.3 bushels per acre.

Three Year Rotation—No. 11

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Oats	2370	49.9	1.48
Fallow	.....	.....	.....
Wheat	2486	16.1	2.57

The yield of wheat in this rotation is 1.4 bushels per acre above the average of all wheat plats. Comparing it with the wheat in No. 16, where the land is summer-fallowed every other year, we find that the yield of wheat in the two rotations has been practically the same, there being an average difference between the two of only one-tenth of a bushel per acre.

A comparison of this rotation with No. 14, which has two crops of wheat and a summer-fallow, shows a difference of only eight-tenths of a bushel per acre in the wheat crops on fallowed land in favor of the crop in No. 11. Following the wheat in No. 11 we have a crop of oats which has averaged 49.9 bushels per acre. In No. 14 we have instead of the oats a second crop of wheat, which has produced an average of 12.9 bushels per acre.

Three Year Rotation—No. 12

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Barley	1932	36.4	1.10
Millet	2867	19.3	2.47
Wheat	2159	14.2	2.53

Three Year Rotation—No. 13

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Barley	1936	39.9	1.04
Peas	2948	20.7	2.38
Wheat	2330	12.9	3.00

We get from these two rotations a comparison of the relative value of peas and millet in the rotation. Wheat following peas in No. 13 has produced a heavier crop of straw, but 1.3 bushels less grain per acre, than has wheat following millet in No. 12. Following peas in No. 13 there has been three pounds of straw to every pound of grain, while in No. 12, where wheat follows millet, there has been but 2.53 pounds of straw to one of grain.

The barley, which follows the wheat in each rotation, has produced 3.5 bushels more grain per acre in No. 13, which has peas, than it has in No. 12, where the third crop is millet.

It would appear from the results of these two rotations that peas have some advantage over millet as a crop in the rotation, but the general averages of all the plats do not point to this conclusion. In neither of these rotations is the yield of either wheat or barley up to the general average for those crops.

Three Year Rotation—No. 14

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat	2537	15.3	2.75
Wheat	2303	12.9	2.98
Fallow			

Three Year Rotation—No. 15

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat	2880	14.3	3.36
Wheat	2850	12.9	3.67
Corn	2363	34.0	.96

These two rotations should be studied together. No. 14 has two crops of wheat and a summer fallow, while No. 15 has two crops of wheat and a crop of corn.

A comparison of the two crops of wheat in each rotation shows very clearly the effect of the immediately preceding

crop. Wheat following wheat has averaged 2.4 bushels per acre less than wheat following summer fallow on the same land, and 1.4 bushels per acre less that wheat following corn. In a favorable season this difference is small, but in a dry year it increases until it amounts to the difference between a good crop and a failure. This was shown by the results in 1900, reported in bulletin No. 79, and has been discussed by the writer in bulletin No. 96 in connection with some results at the Highmore Sub-Station in 1904.

Both crops of wheat in No. 15 have produced heavier crops of straw than have the corresponding crops in No. 14, but the crop has evidently not filled quite as well. The wheat following corn in No. 15 has averaged one bushel less per acre than has the wheat following summer fallow in No. 14. The second crop of wheat which follows wheat has produced exactly the same amount of grain, 12.9 bushels per acre, in each rotation.

Two Year Rotation—No. 16

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat	2810	16.0	2.92
Fallow	.....	.....	.....

Two Year Rotation—No. 17

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat	2989	18.0	2.76
Corn	1924	27.5	.97

Two Year Rotation—No. 18

CROPS	Average Yield per Acre 1898–1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
Wheat	2439	14.3	2.84
Vetch	2680	5.5	8.06

These three rotations should be studied together for a comparison of corn, of summer fallow, and of vetch in alternation with wheat.

No. 17, which has been cropped to corn one year and to wheat the next since 1897, has given an average yield of wheat of 18 bushels per acre. This is the best average yield of wheat obtained in any of the twenty-two rotations under consideration. The yield of corn in this rotation falls below the average of the corn plats because it has in one or two good corn years been badly damaged by gophers. The actual yield of corn that has been obtained is given, but for the reason stated it can not be taken into consideration in judging the value of the rotation.

No. 16, which instead of corn has a summer fallow every other year, has produced an average crop of 16 bushels of wheat per acre. This is two bushels per acre less than the crop in No. 17.

In No. 18 a vetch, **Vicia villosa,** takes the place of the summer fallow in No. 16 and the corn in No. 17. The vetch in itself has not been a profitable crop either for seed or forage, and the yield of wheat following it has only been 14.3 bushels per acre. This is less than wheat following either corn or summer fallow, and is barely equal to the yield of wheat grown continuously on the same ground without manure.

But let us look a little further into the cumulative effects of these three separate methods of preparing the soil for a crop of wheat. As the rotations are completed in two years, each have now been four rounds.

No. 16 represents a farm, one-half of which is summer-fallowed each year and the other half is sown to wheat. The next year the fallowed ground is sown to wheat and the half that grew wheat the year before is in turn summer-fallowed.

In No. 17 one-half the farm is in wheat and the other half is in corn, and these crops change places each year.

In No. 18 vetch takes the place of summer fallow in No. 16 and of the corn in No. 17.

Since this rotation was started each one of the two plats in rotation No. 16 has been summer-fallowed four times and has grown four crops of wheat. Each one of the two plats in rotation No. 17 has grown four crops of corn and four

crops of wheat. Each one of the two plats in rotation No. 18 has grown four crops of vetch and four crops of wheat.

The following table shows the average yields of both straw and grain in each of these three rotations by rounds:

Average Yields Per Acre of Two Year Rotations by Rounds

	No. 16			No. 17				No.. 18			
	Wheat			Wheat		Corn		Wheat		Vetch	
	Straw pounds	Grain bushels	Fallow	Straw	Grain	Stalks	Grain	Straw	Grain	Straw	Grain
1898-9 First Round....	2285	20.7	..	2770	23.1	3025	34.0	2310	22.6	*	
1900-1 Second Round..	2835	17.7	..	2735	16.7	1350	16.2	2100	11.2	2020	....
1902-3† Third Round...	2810	9.0	..	2890	13.5	1000	11.8	2160	5.7	2490	4.3
1904-5 Fourth Round..	3310	13.2	..	3510	16.5	1860	40.3	3045	13.4	3105	8.2

* No record.
† The crop in 1903 was lost by hail.

The evidence offered by this table is not very conclusive in showing that any one of these three methods of cropping depletes the soil of its fertility faster than either of the others. At the end of the fourth round the relative positions of the wheat crops in the three rotations are practically the same as they were in the beginning. The advantage, if any, is in favor of the rotation containing corn over either the one in which the land has laid idle one-half the time or the one where a legume has been grown every other year.

We are obliged to repeat the question asked in bulletin No. 79: "How long can we continue to take a crop off every year without making any return to the soil, as in No. 17, and obtain as good or better crops every year as we do every two years in the case of No. 16?"

Rotations Nos. 19, 20, 21 and 22—Yield of Grain and Straw per Acre

Year	No. 19 Wheat no Manure		No. 20 Wheat Manured every 5 years		No. 21 Wheat Manured every 3 years		No. 22 Wheat Manured every year	
	Straw pounds	Grain bushels	Straw pounds	Grain bushels	Straw pounds	Grain bushels	Straw pounds	Grain bushels
1898	2001	21.5	1840	22.7	2410	18.1	2140	19.8
1899	2380	20.7	1800	20.0	2260	18.1	2670	22.1
1900	1003	3.7	1110	3.1	1640	2.7	2100	4.1
1901	2580	16.1	2490	16.8	3100	14.1	2950	14.1
1902	2290	8.5	2510	6.5	2710	9.0	3640	11.0
1904	3200	7.5	3500	8.3	3280	4.5	3950	7.5
1905	2680	22.8	2790	22.7	3800	23.3	3920	24.7
Average	2310	14.4	2291	14.3	2743	12.8	3053	14.8

The yield of these four plats are given for each year. No. 19 is cropped every year to wheat and no manure of any kind is returned to the soil. No. 20 is cropped to wheat every year and is manured once in five years. It was manured in 1897, and was manured again before the crop in 1902. No. 21 is cropped to wheat every year and is manured every three years. It was manured in preparation for the crops of 1897, 1900 and 1903. No. 22 was manured for the crop of 1897 and has been manured every year since.

The results are in general something of a disappointment. The general averages of No. 19 and No. 20 are almost exactly the same. In 1905, which was a year of normal crop production, there was practically no difference in the yields from plat No. 19, which has grown eight crops of wheat without manure, and plat No. 20, which has grown the same number of crops of wheat, but had had two coats of manure during the period. Plat No. 21, which has had in the same time three coats of manure, has to its credit a heavier yield of straw than either No. 19 or No. 20, but has a poorer average yield of grain. In 1905, which was, as said before, a year of normal crop yields, Plat No. 21 produced 1,120 pounds more straw per acre, but only one-half a bushel more grain per acre than plat No. 19. Plat No. 22, which has been manured every year, has a still higher average yield of straw per acre than has No. 21. The yield of grain has not increased, how-

ever, in proportion to the increase in the yield of straw. No. 22 has averaged 743 pounds more straw per acre, but only four-tenths of a bushel more grain per acre than has No. 19, which has had no manure at all. In 1905 there was a difference between these two plats of 1,240 pounds of straw and only 1.9 bushels of grain per acre in favor of No. 22.

These results show very conclusively that it is not profitable on our soil to apply manure directly to wheat or to land that grows wheat alone. But by this we do not mean to say that manure should not be used at all, or even that it can not be used profitably. Attention is called to the facts brought out in the discussion of the results from the four year rotations No. 7 and No. 9, one of which has no manure, while the other has manure applied to the soil in preparation for a corn crop once in four years.

Our general conclusion from these experiments is that the place to put manure is on land intended for corn. The crop of corn itself will be benefited and the crops of small grain that follow the corn will derive more benefit from the manure than they would if it were applied to them direct.

Rotations Nos. 23 and 24

The experiments in crop rotation as originally planned did not include any rotations in which the land was laid down in a perennial grass crop. In the spring of 1902, however, two rotations introducing brome grass were begun.

No. 23 requires six years for the completion of one round, and No. 24 is completed in five years. In No. 23 wheat is disked in on corn ground, and with the wheat is sown from 15 to 20 pounds of brome grass seed per acre. The next year a crop of either brome grass hay or seed is secured. The year following, which is the third year of the rotation, a maximum crop of either hay or seed is harvested from the brome grass. The fourth year about two-thirds of a crop of hay is cut early in June and the ground is then broken and seeded to flax. Following the flax a wheat crop is grown, and following the wheat a crop of corn. This completes the round of the rotation, and wheat and brome grass are sown on the corn ground again.

No. 24 is the same as No. 23, just described, except that the year of brome grass and flax is omitted and the rotation is completed in five years. In this rotation the brome grass sod is broken in the fall after the crop of hay has been secured the second year.

Brome grass sod handled in this way does not seem to rot sufficiently to produce a full crop of wheat the following year. In No. 23, where the sod is broken in June and sowed to flax the crop of flax has been very poor, but the wheat crop the following year has been a half larger than it has been on sod broken in the fall in No. 24. While we have not sufficient data to justify a conclusion, the writer is inclined to believe that the greatest profit will be obtained from brome grass that is broken early in the season and allowed to lay bare through the summer. As brome grass starts early in the spring, land handled in this way would afford a large amount of spring pasturage before it was broken. It might be well to state in this connection that no difficulty is experienced in killing out brome grass whatever season of the year it is broken. A brome grass sod is stiffer and harder to work than either timothy or clover sod. It is somewhat intermediate in this respect between a timothy sod and the native prairie sod.

With the exception of the one crop following brome grass broken in the fall, the wheat in both of these rotations has for the past two years been the best both in yield and quality of the wheat in any of the rotations.

The corn in these rotations has been the best, too, of any of the corn plats. Its yield has been heavier, and it has both in 1904 and 1905 been from one week to ten days earlier than corn on old land. In 1904 this was time enough to make the difference between a crop of sound dry corn and a crop of soft corn.

Either one of these rotations could be lengthened or modified to meet the requirements of any farm. A crop of barley or oats could be introduced or could take the place of one of the wheat crops. The grass could be allowed to stand a year or two longer, or clover and timothy could be sown instead of brome grass.

Some sod crop should enter into the rotation practiced on every farm. Such crops clean the land of weeds, increase the supply of humus in the soil, and the roots prevent the soil from blowing. Laying the land down in sod restores it in a measure to its virgin condition, a thing so desirable as to commend itself to every one who has to do with the soil.

In the estimation of the writer, the introduction of grasses into the rotation of every farm is one of the most needed things in the agricultural practice of at least the eastern part of the state today. A pasture or meadow is quite generally regarded now as a more or less permanent fixture of the farm. This is a mistaken practice that we are gradually getting away from. It is comparatively easy to get a stand of brome grass, timothy or clover, and the seeding is not expensive. About the second year these are at their best, and after that they usually run down. Instead of letting them stand longer a greater profit would be obtained by breaking them up, getting the benefits of crops grown on new land, and sowing down new fields and reaping the benefits of a new and vigorous sod.

The following tables give the average yields per acre from rotations Nos. 23 and 24 for the years 1902, 1904 and 1905:

Six Year Rotation—No. 23

CROPS	Average Yield per Acre—1902-1905	
	Straw pounds	Grain bushels
Wheat	3175	18.3
Brome hay	4950	.....
Brome hay	6525	.....
Brome hay	3650	.....
Flax	545	4.3
Wheat	2630	19.1
Corn	3190	62.8

The third crop of brome hay and the crop of flax are both secured in one year.

Five Year Rotation—No. 24

CROPS	Average Yield per Acre—1902-1905	
	Straw pounds	Grain bushels
Wheat	3135	19.7
Brome hay	4375	.....
Brome hay	6650	.....
Wheat	1485	12.7
Corn	3590	57.0

The Effects of the Immediately Preceding Crop Upon the Yield of Wheat and Oats, as Determined by the Averages of Six Year's Crops

It has probably been noted by the reader in following the discussions of the separate rotations in the foregoing pages that in almost every instance the one thing that seemed to determine the yield of each separate crop of small grain was the influence of the immediately preceding crop. In the following tables we have collected the data bearing on this question in a form to facilitate comparison:

Wheat After Corn

Rotation No.	Average Yield per Acre 1898-1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
4	2817	16.1	2.90
6	2836	14.9	3.16
7	2468	14.5	2.65
9	2958	17.5	2.81
15	2880	14.3	3.36
17	2989	18.0	2.76
Averages	2824	15.9	2.94

Wheat After Fallow

Rotation No.	Average Yield per Acre 1898-1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
3	2722	15.8	2.88
11	2486	16.1	2.57
14	2537	15.3	2.75
16	2810	16.0	2.92
Averages	2639	15.8	2.78

Wheat After Millet

Rotation No.	Average Yield per Acre 1898-1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
1	2642	17.1	2.57
5	2981	15.6	3.17
8	2253	13.6	2.77
12	2159	14.2	2.53
Averages	2509	15.1	2.76

Wheat After Peas

Rotation No.	Average Yield per Acre 1898-1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
2	2617	14.9	2.93
4	2947	15.5	3.17
6	2920	13.0	3.74
13	2330	12.9	3.00
Averages	2703	14.1	3.21

Wheat After Oats

Rotation No.	Average Yield per Acre 1898-1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
3	2431	14.5	2.80
7	2005	12.7	2.63
9	1958	14.5	2.25
10	2047	12.9	2.63
Averages	2110	13.6	2.58

Wheat After Wheat

Rotation No.	Average Yield per Acre 1898-1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
14	2303	12.9	2.98
15	2850	12.9	3.67
19	2310	14.4	2.67
20	2291	14.3	2.67
21	2743	12.8	3.55
22	3053	14.8	3.44
Averages	2591	13.7	3.16

Wheat After Potatoes

Rotation No.	Average Yield per Acre 1898-1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
2	2632	15.9	2.76

Wheat After Vetch

Rotation No.	Average Yield per Acre 1898-1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
18	2439	14.3	2.84

Exclusive of rotations Nos. 23 and 24, there are grown each year thirty plats of wheat. Six of these follow corn, four follow summer fallow, four follow millet, four follow peas, four follow oats, six follow wheat, one follows potatoes, and one vetch.

The lowest yield of wheat grown on corn ground is 14.3 bushels in rotation No. 15, the highest is 18 bushels in rotation No. 17. The average yield of the six plats of wheat following corn is 2,824 pounds of straw and 15.9 bushels of grain per acre. This is a little more straw, but exactly the same amount of grain as has been produced by the crop of wheat on potato ground in rotation No. 2. It is a heavier average yield of both straw and grain than has been produced by wheat following any other crop.

The next best average yield of wheat has been produced in the four rotations where that crop is grown on summer fallow. The lowest yield of grain following summer fallow is 15.3 bushels, and the highest is 16.1 bushels per acre. The average of the four plats is 2,639 pounds of straw and 15.8 bushels of grain per acre. In some rotations and some seasons wheat on fallowed land has produced a better crop than it has on corn ground, but in other years and in other rotations the reverse has been true. There is on the whole very little

choice between a crop of corn or potatoes and a summer fallow as a preparation for a crop of wheat.

The four plats of wheat following millet come next in order with an average yield of 15.1 bushels of grain per acre. The lowest yield of wheat on millet land is 13.6 bushels and the highest 17.1 bushels per acre. This last is in rotation No. 1, where the millet follows flax.

The yields of the four crops of wheat following peas range from 12.9 bushels per acre in rotation No. 13, to 15.5 bushels in rotation No. 4, where the peas are plowed under as a green manure. The average yield of straw from wheat following peas is higher than in any other group except those on corn ground, but the grain has only averaged 14.1 bushels per acre. The average of the one plat of wheat following vetch is only 14.3 bushels per acre.

The average yield of four plats of wheat following oats in the rotations is 2,110 pounds of straw and 13.6 bushels of grain per acre.

The average yield of six plats of wheat following wheat is 2,591 pounds of straw and 13.7 bushels of grain per acre. In dry years wheat following wheat has been better than wheat following oats, but the general average shows for our soil and climate but little difference in the yield of wheat following these two crops.

Oats After Wheat

Rotation No.	Average Yield per Acre 1898-1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
2	2772	49.3	1.75
5	2923	52.1	1.75
7	2323	49.6	1.47
9	2407	55.6	1.35
11	2370	49.9	1.48
Averages	2559	51.3	1.56

Oats After Corn

Rotation No.	Average Yield per Acre 1898-1905		Pounds of Straw to One of Grain
	Straw pounds	Grain bushels	
3	2753	54.6	1.57
8	2521	52.5	1.50
11	2385	50.5	1.47
Averages	2553	52.5	1.51

Five plats of oats are grown each year following wheat and three plats following corn. The lowest average yield following wheat is 49.3 bushels per acre, the highest is 55.6 bushels per acre, the average of the five plats is 51.3 bushels per acre.

Three plats of oats are grown on corn ground each year. The average yields of these three plats have been 50.5, 52.5 and 54.6 bushels per acre respectively, the average for the three being 52.5 bushels. The average yield of straw from oats following wheat is almost exactly the same as from oats following corn.

These general averages show that wheat is a more particular crop in its requirements than is oats. We have a difference of only 1.2 bushels of oats per acre between the crop grown following wheat and the crop following corn, but with the wheat we had an increase of 2.6 bushels of wheat per acre in favor of the crop grown on corn ground against the crop grown following oats, and practically the same difference where wheat was the preceding crop. This being the case where the three crops, wheat, oats and corn, are to be grown, the wheat should follow the corn and the oats should follow the wheat. With the crops in this order the wheat crop will be considerably larger and the oat crop very nearly as large as if the places of the wheat and oats were changed.

CONCLUSIONS

1. The best average yields of wheat have been obtained in those rotations where that crop follows either corn or potaties. Following these crops in the order of their merit as a preparation for the growth of wheat comes summer fallow, millet, vetch, peas, wheat and oats.

2. The drier the season or the more unfavorable the conditions for the production of a maximum crop of straw and grain, the more important becomes the introduction of a cultivated crop into the rotation.

3. Wheat being a more particular crop than oats, it should have a better place in the rotation than should the latter crop.

4. Flax is not more exhaustive of the fertility of the soil than are the other grain crops.

5. The growth of a nitrogen-gathering crop, as represented by Canada field peas and by vetch, has increased the growth of straw in the following crops without materially increasing the yield of grain. This has been the most marked where the peas have been plowed under as green manure, or "hogged off" on the land.

6. Plowing under peas for green manure has not as yet shown any benefits over a summer fallow.

7. At the end of eight years land that has grown wheat and corn alternately is producing better crops of wheat, of both straw and grain, than is similar land upon which wheat has been alternated with vetch and with summer fallow.

8. It has not on our soil proven profitable as yet to manure land that grows wheat alone.

9. It has proven decidedly profitable to manure land for corn. Not only has the yield of the corn crop been increased, but the effects of the manure have been shown in the increased yield of the following crops for at least four years.

10. The best rotations will include some perennial grass in which the land is laid down in sod for a short term of years. Present results indicate that brome grass is well adapted to use in short rotations.